Cerebral convergence of sentence processing in speech and reading: Effects of differences in reading skill

Donald Shankweiler[1,2], David Braze[1], W. Einar Mencl[1], Whitney Tabor[1,2], Kenneth Pugh[1,3], R. Todd Constable[3], Robert K. Fulbright[3], James S. Magnuson[1,2], Julie A. Van Dyke[1]

[1]Haskins Laboratories, [2]University of Connecticut, & [3]Yale University School of Medicine

University of Connecticut

Haskins Laboratories — THE SCIENCE OF THE SPOKEN AND WRITTEN WORD

The Problem

The potential to derive equivalent meanings from speech and print is a characteristic of the human brain that makes literacy possible. Full achievement of this supramodal potential requires years of instruction and practice. Hence, integration of the brain's response to sentence material in the two modalities can be expected to vary as a function of reading skill. Although studies from our laboratory and elsewhere have yielded evidence of a supramodal cerebral language system (e.g., Constable et al, 2004; Michael et al, 2001; Spitsyna et al., 2006), its architecture has not been clearly delineated (Poeppel, 2006), and the influence of reading experience on this architecture has only recently begun to be studied (see Castro-Caldas et al. 1998; Shankweiler et al., 2008).

Research Aims

Aim 1: to determine the location of brain regions with supramodal potential for sentence comprehension.

Aim 2: to probe the hypothesis that high reading skill is associated with strong convergence of responses to speech and print within the hypothesized supramodal regions.

Method

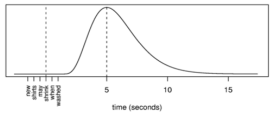
Modality indifferent brain regions supporting speech and print were identified by fMRI scan during comprehension of spoken and printed sentences that varied in difficulty.

Participants: 36 young adult readers, aged 16-24, representing a wide range of skill levels, with Full Scale IQ 80 or above.

Experimental materials: matched printed and spoken sentences, with controlled vocabulary, that were either well formed or contained anomalies of syntactic form or pragmatic content.

Examples of stimulus sentences for fMRI
non-anomalous: Rabbits will chew leafy greens.
pragmatic anomaly: Baskets will chew leafy greens.
syntactic anomaly: Rabbits are chew leafy greens.

Task in the magnet: Semantic categorization. Does the sentence mention a plant or a plant product? [Participants were **not** asked to make anomaly judgments.]

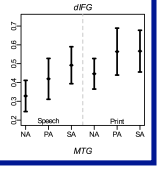


Multiple regression was used for single subject, event-related analyses. At each voxel, signal intensity over time was modeled with a simulated hemodynamic response function. The time to peak, 5 sec, was based on previous work in our lab. The peak was temporally aligned to the onset of the critical word, the verb, in each sentence, as shown.

Research Aim 1

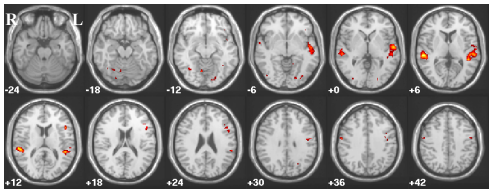
To identify candidate supramodal language areas, we employed a novel whole-brain analysis designed to illuminate brain regions that show a similar pattern of responses to the three experimental sentence conditions regardless of input modality.

- For each modality separately, we extracted the 3-vector activation levels for non-anomalous, pragmatically anomalous, and syntactically anomalous sentences, respectively. The vectors characterize the shape of activation for the three sentence types within a modality. We then compared the shape of this response vector for speech versus print using a cosine-based metric.
- In order to assess the supramodal potential of the entire brain in a completely unbiased manner, we computed the cosine of the angle between the print vector and the speech vector for each voxel within the brain, a value that can vary from -1 to 1, like an r-value. As an example, the figure on the right shows the pattern of activation for a spherical region in IFG. *Note that the pattern across the three sentence types is very similar in both modalities.* The cosine metric quantifies this similarity.



Results Aim 1

- This analysis is based only on the more skilled readers in the sample (upper half, N = 18).
- The cosine vector approach allowed us to identify all voxels throughout the brain that produced similar activation patterns for each modality across the three experimental conditions (Braze et al., submitted). Figure [6] shows a composite map of averaged cosine values across the brain ≥ .6
- Supramodal regions were found in both hemispheres, but with nearly twice the total volume on the left.
- The largest volume supramodal site was located in the left superior temporal region.
- The left inferior frontal gyrus and the medial frontal gyrus bilaterally also yielded large volumes.
- One posterior cortical site, fusiform gyrus, and one cerebellar site, culmen, was clearly larger on the right, consistent with the likelihood that at least some language components are bilaterally represented.



Research Aim 2

To investigate the hypothesized influence of individual differences in reading skill on speech-print convergence, we carried out an analysis employing all 36 participants.

- For this analysis: Anatomic ROIs were specified, at presumptive unimodal and heteromodal zones of left-hemisphere association cortex (based on studies of nonhuman primates).
- To obtain a quantitative measure of convergence, we computed a Convergence Index for each participant for each ROI. *Convergence Index* was defined as the proportion of voxels within each anatomically-defined ROI that showed a difference in activation for anomalous and nonanomalous sentences *in both modalities*.
- We then determined whether reading skill measures correlate with convergence at some or all modality convergent (supramodal) regions (Shankweiler et al, 2008).

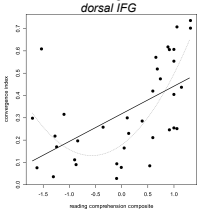
Results Aim 2

- Highest values of the correlation across participants of the Convergence Index and predetermined measures of skill in reading comprehension were found at inferior frontal regions.
- Scatter plot shows that values of the Convergence Index at the dorsal portion of IFG were positively correlated with skill in reading comprehension, r = .55, p = .0005. (A curvilinear fit to the data yields a correlation of .73).

Convergence Index at each anatomically-defined region of interest

Region	Mean	SD
Dorsal IFG	0.332	0.215
Ventral IFG	0.305	0.190
Fusiform G	0.253	0.165
Posterior STG	0.244	0.167
Motor face	0.243	0.157
Calcarine S.	0.231	0.173
Posterior MTG	0.229	0.135
Transverse TG	0.182	0.180
Supramarginal G	0.166	0.153
Angular G	0.080	0.141

Correlation of convergence and skill at dorsal IFG



- Other measures of skill (e.g., word and nonword reading) also show (slightly lower) correlations at IFG.
- Posterior heteromodal ROIs did not yield significant correlations with skill.

Summary and Conclusions

- In the analysis based on skilled readers, convergence was discovered primarily in temporal and frontal regions, consistent with earlier work from our laboratory (Constable et al., 2004) and other findings that employed different linguistic materials, different tasks, and different measures of convergence (e.g., Michael et al., 2001; Spitsyna et al., 2006).
- Supramodal regions of convergence are located in both hemispheres but predominantly in the left hemisphere. Hypothesized function: to bind speech and print into an integrated system of representation.
- The left superior temporal region, identified as a supramodal zone by all studies, proved to be the largest supramodal zone.
- Left inferior frontal gyrus is also prominent among the supramodal regions, as Constable et al, (2004) and Homae et al. (2002) found.
- The analysis of individual differences finds that, as hypothesized, a well-integrated supramodal language brain is a characteristic of skilled readers whereas in unskilled readers the system is poorly integrated.
- Supports the hypothesis that degrees of reading skill can be interpreted as the graded cortical convergence of print representations with those of spoken language.
- The left inferior frontal region, identified in both analyses (under Aim 1 and Aim 2) as a site of speech-print integration, was the major focus of reading skill differences in convergence.
- Further research should seek to identify which components of reading are tied to modality (unimodally represented in visual regions) and which are supramodal.

References

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